Version JAB/KAS/V4

EGT3
ENGINEERING TRIPOS PART IIB

Monday 2 May 2022 9.30 to 11.10

Module 4D10

STRUCTURAL STEELWORK

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 4D10 Structural Steelwork Data Sheets (17 pages)
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationery from the Examination Room.

1 A $533 \times 210 \times 82$ UB of grade S355 has a length of 12 m and is simply supported at its ends. Out-of-plane displacements at the mid-span are prevented but the beam is otherwise unrestrained along its length. The ends are free to warp but do not twist about the longitudinal axis. The root radius of the UB is 13 mm.

A moment, M, is applied at one end of the beam about its major axis. The beam also carries an axial force, P. Self-weight may be neglected.

(a) Determine the bending capacity of the beam when $P = 0$. [40%]

(b) Determine the compressive capacity of the beam when $M = 0$. Hint: determine first the class of cross-section. [40%]

(c) Assuming a linear $P-M$ interaction diagram, assess whether the beam can withstand the following combination of factored design loads: $P = 300$ kN and $M = 300$ kNm. [20%]

2 A composite bridge deck consists of a concrete slab, of thickness 200 mm, cast onto plate girder beams spaced at 3.5 m intervals. Each beam has a length of 27 m, and consists of a 1200 mm $\times$ 14 mm vertical web plate and 350 mm $\times$ 30 mm top and bottom flanges. The steel grade is S355 and the concrete has a characteristic (cylinder) strength of 30 MPa.

The bridge deck is to be designed for a vehicle load, represented by a point load of 200 kN (unfactored value), moving along the bridge.

(a) Check whether the bending capacity of the beam is adequate. [40%]

(b) Design a shear connector configuration which ensures a full composite action at mid-span, at ULS. Assume the ultimate tensile strength of the connectors to be 450 MPa. [20%]

(c) The bottom flange of the beam contains a transverse butt weld at the quarter-points of the span, which places the bottom flange in detail category 71 for fatigue calculations. Determine the number of load cycles, *i.e.* passages of the vehicle over the bridge, before fatigue failure is expected to take place at these locations. [40%]

3 (a) You are tasked with designing a completely new product range of Universal Beams in grade 960 MPa steel, for use in buildings.

(i) Explain which principles would guide you in your design. How would these sections differ from the currently available range in S235-S420 steel? [15%]

(ii) Determine an appropriate Class 3 limit for the web and the flanges from first principles. Hint: the critical elastic buckling stress, σ_{cr}, of a square plate of thickness, t, and side-length, b, which is simply supported on all four sides and subject to pure bending, is:

$$\sigma_{\text{cr}} = \frac{K\pi^2 E}{12(1-\nu^2)}\left(\frac{t}{b}\right)^2$$

with $K = 23.9$ and ν as Poisson's ratio. [25%]

(b) A square box section with an (outside) width of 200 mm and a wall thickness of 5 mm, is to be used as a pin-ended column of length 15 m. Using the 'c' buckling curve, determine the column capacity when:

(i) grade S235 steel is used; [25%]

(ii) grade 960 MPa steel is used. [25%]

(iii) Comment on your results in parts (b.i) and (b.ii). [10%]

4 A welded plate girder beam consists of a vertical 1200 mm × 14 mm web and 350 mm × 30 mm top and bottom flanges. A bolted splice connection in the beam has the layout shown in Fig. 1. The bolts are M22, of grade 8.8. The steel grade of the beam and splice plates is S355, where f_u = 490 MPa.

Check whether the connection can resist a moment of 3500 kNm in combination with a shear force of 1500 kN, both as factored values. Hint: apply the principle that all parts of the beam, *i.e.* the web and the flanges, need to be connected for the share of forces and moments they carry. [100%]

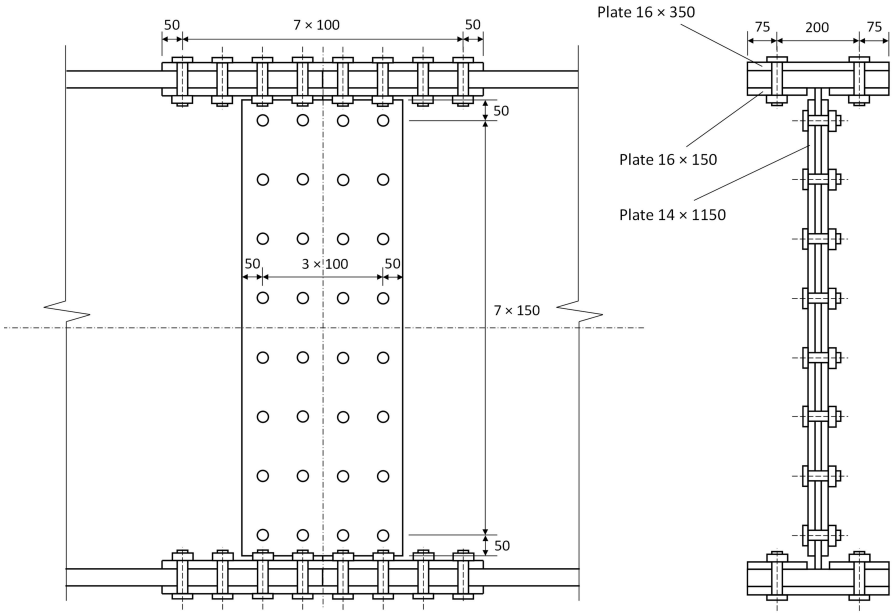

Fig. 1

END OF PAPER

Answers:
(Allow for a small variation in numerical answers which are derived from reading charts and graphs in the datasheets.)

1(a) 395 kNm.
1(b) 959 kN.
1(c) for $P = 300$ kN, maximum moment from interaction diagram has $M = 271$ kNm, which is smaller than the specified moment; thus, the combination cannot be carried safely.

2(a) Required moment capacity (for simply-supported beams) is 4492 kNm; design capacity is 9478 kNm; thus, there is adequate capacity.
2(b) $P_{\mathrm{Rd}} = 110$ kN and 115 connectors.
2(c) 2.205×10^6 cycles.

3(a.i) Standard checks are for local buckling in compression, bending, and in shear; elements typically need to be stockier because of higher yield limit.
3(a.ii) For outstand in compression, $c/t < 9.2$; for web in bending, $c/t < 68/7$; for web in shear, $c/t < 24.7$.
3(b.i) 183 kN; (b.ii) 197.1 kN; (b.iii) both results are close to elastic predictions from Euler and, thus, the benefits of a higher yield stress are not realised.

4) Check splice plates for yielding, bolt groups for shearing, bolt holes for bearing, outstands and web for local buckling; see crib for full details of all checks.